EFFECTS OF THINNING AND FERTILIZING ON PRODUCTION OF WESTERN WHITE PINE SEED

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COVER PHOTO

Cathedral Peak
seed production area,
Coeur d'Alene National
Forest, after thinning.

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INTRODUCTION

Artificial regeneration has increased markedly during recent years. Between 1950 and 1960 the number of acres planted annually in the United States by all agencies increased from about 500,000 to 2,100,000. Subsequently, planting declined but has apparently leveled off at about 1,300,000 acres per year (31).[1] To provide enough nursery stock for this tempo of planting, production of seed of good genetic quality needs to be increased and stabilized.

Seed production areas and seed orchards have been established to fill this need. A seed production area is typically a stand of desirable trees set aside for seed production and usually given special cultural treatments to increase seed production. In contrast, a seed orchard is a plantation of trees (established by grafting or from cuttings or seedlings) that have been rigorously selected and have been or are being tested to determine their genetic worth. Typically, seed production areas provide a temporary source of seed until seed orchards come into production and provide markedly improved seed. The number of seed production areas is increasing rapidly--already 10,068 acres are now devoted to this use in the United States (31).

In 1959 the Northern Region of the U.S. Forest Service (Region 1) established a western white pine seed production area near Cathedral Peak in Coeur d'Alene National Forest to provide good quality seed from a highly regarded source. Experiments were begun in this area to determine the effects of thinning and fertilizing upon tree, cone, and seed traits as well as on growth (24).

BACKGROUND

Literature describing the establishment and management of seed production areas has been summarized by Rudolf (22, 23) and Zobel et al. (33). A general review of factors affecting seed production, including insect and disease problems, was published by Hoekstra et al. (13); and Matthews (16) published an excellent review of seed production. A brief review of the differentiation of floral primordia and the effects of thinning and fertilizing upon strobilus and cone production[2] of fruiting-age trees is pertinent to the results presented.

The stage of physiological development of a tree and the time of differentiation of floral buds are two of the most important factors affecting cone production. It is well known that juvenile trees typically do not flower, whereas those in the adult stage are physiologically capable of flowering. In this paper we are concerned only with trees in the adult stage and with the factors that stimulate primordium and cone production.

The time of visual recognition (microscopic and macroscopic) of floral primordia in the soft pines is later than in the hard pines. Present evidence indicates that hard pines are typically more advanced in primordium development at any given time than

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[1] Numbers in parentheses refer to items in Literature Cited.

[2] To distinguish between two arbitrary developmental stages of the female reproductive organ in this paper, the term <u>strobilus</u> is used to designate this structure as the newly formed organ, while the overwintering form and all stages thereafter are termed <u>cone</u>.

soft pines; thus it is not unreasonable to expect that the beginning of differentiation of floral structures may be earlier.

Male and female strobili of ponderosa pine and Austrian pine are detectable by eye in September. Mergen and Koerting (17) reported that male and female floral primordia of slash pine were recognizable by mid-July and late August, respectively, of the year before flowering. However, floral primordia of soft pines are not as easily detectable.

In repeated histological work with eastern white pine, Ferguson (8) was never able to find male strobili in the fall. They were visible only by late April or early May of the year of flowering. She found female strobili visible (histologically) only in late April or early May.

Owston (19) found no reproductive primordia in fall and winter buds of young eastern white pine even though female cones were present on some study trees.[3] He believed this was due to lack of visible differentiation until the following spring. Although the same might be true for male strobili, Owston's trees produced negligible numbers of male cones, and failure to identify them could well have been due to their absence from the samples. Owston found the developmental cycle in southeastern Michigan such that male primordia might be differentiated, but not necessarily visible, in early July. Female cones might be differentiated toward the end of August, but would not look any different than vegetative primordia until the following spring.

Stephens (28) found fully differentiated male strobili in mid-November collections of terminal buds from four eastern white pine trees, but not in late August collections. However, he did not report finding male strobili in all trees; hence it is possible that considerable variation might exist among individual trees. Although differentiation of female primordia "may possibly occur the season prior to flowering," the "actual development of the strobili does not occur until resumption of growth by the bud in early spring," Stephens said.

Konar and Ramchandani (14) working with Pinus wallichiana Jacks. (=P. griffithii McClelland) reported that male strobili were "initiated" from the middle of October to the beginning of November and female strobili were "initiated" in February. In short, evidence indicates that in the soft pines, (a) male primordia are differentiated and microscopically visible before female primordia and (b) that male primordia are microscopically visible in late fall, but for female primordia differentiation occurs in the spring of the following year.

Generally, the release of seed trees increases production of strobili and cones; cone production is inversely proportional to stand density (1, 5, 6, 10, 20, 32). Florence and McWilliam (9) found that the stand density that maximizes cone production per tree is much lower than one giving maximum production per acre. For young slash pine, the density for optimum production was approximately 120 trees per acre. Pollen production closely followed the trends in cone production. Allen and Trousdell (1) found that release significantly increased the proportion of sound seed of loblolly pine; Reukema (21) observed no increase in sound seed following thinning of Douglas-fir stands. In years of generally light strobilus formation, release apparently has little effect on strobilus production (20, 21).

Fertilizing is definitely known to stimulate cone and seed production in numerous forest species, but results are too varied to permit a definite prescription (16). The amount of response depends greatly upon the genetically determined ability to flower, kind and time of treatment, and conditions of the environment. Steinbrenner

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[3]Also personal communication from P. W. Owston, July 2, 1968.

et al. (27) found that a combined application of nitrogen and phosphorus fertilizers increased cone length and seed weight in Douglas-fir. The highest treatment levels of both fertilizers caused the greatest increase in seed weight. Mergen and Voight (18) reported that fertilizer treatments produced heavier slash pine seeds. However, in one previous experiment with western white pine, fertilizer was ineffective in stimulating strobilus production of fruiting-age trees (2).

Much less is known about fruiting response related to time of differentiation of flower buds and timing of cultural treatments. Applying fertilizer to precede or coincide with differentiation of flower buds may markedly increase cone production (30). Owston's investigations of eastern white pine in Michigan indicated that application of fertilizer in August could influence existing primordia that have the potential for becoming male cones and could possibly affect both the number and condition of the primordia that have a female potential.[4] Since floral primordia could abort, presumably at any time between differentiation and anthesis, improving nutrition (through fertilizing) or increasing moisture availability (through thinning) any time after initiation could reduce abortion and thus increase the number of strobili available for pollination and subsequent development. Some evidence of reduction of abortion is available (27).

Insects may cause serious losses to cone crops of both eastern and western white pine (3, 12). Larvae of the cone beetle, <u>Conophthorus monticolae</u> Hopkins, and larvae of the cone moths, <u>Eucosma rescissoriana</u> Heinrich and <u>Dioryctria abietella</u> (D.&S.), may destroy or severely damage western white pine cones.

ESTABLISHMENT OF THE SEED PRODUCTION AREA AND EXPERIMENTAL DESIGN

Personnel from the Intermountain Forest and Range Experiment Station and the National Forest System cooperated in selecting the site of the seed production area. Some of the criteria for selection of the site were: presence of young, high quality trees in natural stands or plantations; trees in plantation from a known source; presence of cones on trees; accessibility of site in spring and fall; flatness of terrain; absence of debris and brush; proximity to water; and homogeneity of soil. Meeting all these requirements was difficult. The site selected from 15 alternatives on the Coeur d'Alene National Forest was a young plantation that was producing exceptionally large numbers of cones, and it was located on relatively level terrain. The growth of this stand exceeded that of natural western white pine stands of comparable age (4). Some disadvantages were its relative inaccessibility, lack of water, and lack of exact information about the provenance of the planted stock it originated from.

In September 1959, two areas (Units 1 and 2), each approximately 3 acres and located about 1 mile apart, were selected in a 40-year-old plantation near Cathedral Peak, Coeur d'Alene National Forest, Shoshone County, Idaho. Later that fall, each unit was subdivided and thinned. One subunit was thinned to a spacing of approximately 30 by 30 feet (48 trees per acre) and the other to 20 by 20 feet (109 trees per acre). Before thinning, the spacing was approximately 9 by 9 feet (538 trees per acre).

Seed trees were selected on the basis of freedom from lethal blister rust cankers, spacing, fruitfulness, form, and vigor. When the area was thinned, a small amount of slash was chipped. The remainder of the slash was chipped in June and July 1960, and left in piles. Tree boles too large to chip were piled within the area. Trees were pruned to about 8 feet, and 14-inch aluminum bands were attached to all trees to prevent squirrels from cutting the cones. The total cost for establishment of the area, excluding overhead and research costs, was about $1,000 per acre. Because of the high cost of thinning, chipping, and clearing, isolation strips were not provided.

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[4] Ibid.

In June 1960, three circular 1/10-acre sample plots were established in each subunit and three in the unthinned plantation surrounding each unit. Thus, nine sample plots were established in or near each of the two units.

Thinning did not produce the planned number of trees per acre on the sample plots. Angle summation (25) and counts of number of trees per 1/10-acre plot in 1962 indicated that the actual average spacing on the six thinned sample plots in Unit 1 was similar: 87 and 84 trees per acre for the 20-foot and 30-foot spacings, respectively. In Unit 2, spacings of the thinned stands were substantially different: 93 trees per acre for the 20-foot spacing and 60 trees per acre for the 30-foot spacing. Combined data for both units indicated the difference in density (angle summation data) between the 20-foot and 30-foot spacings was not significant ($P>.10$). In analysis of data for the three levels of spacing, the most significant results were the differences between thinned and unthinned stands.

In each level of spacing, two of the three plots were fertilized in August 1960 and 1961 to coincide with early-fall precipitation. Fertilizer treatments were assigned at random. One plot received approximately 300 pounds per acre each of nitrogen (N), phosphorus pentoxide (P_2O_5), potassium oxide (K_2O) in a 13-13-13 commercial fertilizer.[5] The per-acre application rates for elemental nitrogen, phosphorus, and potassium were approximately 312, 136, and 259 pounds, respectively. This treatment was designated NPK. The other fertilized plot received approximately 300 pounds per acre of elemental nitrogen in the form of ammonium nitrate (NH_4NO_3). The third plot was untreated.

The three dominant trees nearest to plot center were selected as sample trees for counts of male and female strobili and for cone collections. Additional cone collections were made in the next three dominant trees closest to plot center.

In late June or early July of 1960, 1961, and 1962, each of the three sample trees nearest to plot center was climbed, and the male and female strobili were counted. Each year the numbers of strobili and cones were recorded for all branches in whorls originating from 1954 through 1957; some strobili and cones were counted on whorls 1955 to 1958. An analysis of variance of 1961 strobilus production data indicated between-tree variance was approximately twice that of between-whorl variance. Consequently in 1962, strobilus and cone counts were made on six sample trees instead of three. The strobilus count of 1 year was checked and corrected by the cone count of the following spring.

In late August or early September of 1960, 1961, and 1962, cones were counted and collected from the six sample trees. Climbers were instructed to collect six uninfested cones from the sample whorls. The number of cones and their condition (infested or uninfested) on the sample whorls were recorded at that time. In the unthinned plots, cones were covered by cloth bags before collection to prevent squirrel cutting.

The cones from each sample tree were spread out to dry in a greenhouse. Seeds were extracted with extreme care and cone lengths were measured. Seeds were dewinged and winnowed, and hollow and sound seeds were counted; sound seeds were weighed.

Despite precautions, some infested cones were collected. In 1961 and 1962, insect attack was so heavy that infested cones had to be collected from some trees. Seed from infested cones was extracted separately.

Branches for male strobilus counts were chosen at midcrown in the center of the male-flowering portion of each sample tree. One branch was selected on the north side and one on the south side of the tree. Male strobilus clusters were counted on these

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[5]Fertilizer was supplied by Cominco Products Inc., Spokane, Washington.

branches of each of the three sample trees. The number of strobili per cluster was determined by sampling and the total number of strobili for each branch was estimated (number of clusters X average strobili per cluster).

Analysis of variance was used to determine the effects of spacing and fertilizing upon the following variables: female strobilus production, male strobilus production, percentage of hollow seed, seed weight, cone length, number of seed per centimeter of cone length, seed production per tree, and seed production per acre.

RESULTS

Female Strobilus Production

Strobilus production increased in response to thinning (table 1). The difference between the thinned and unthinned stands was significant ($P<.05$) in 1960 and highly significant ($P<.01$) in 1961 and 1962. Strobilus production per whorl in the 30- by 30-foot spacing was significantly greater than that in the 20- by 20-foot spacing in 1960 ($P<.06$) and 1962 ($P<.025$).

Response to fertilizing was less marked, but strobilus production increased significantly in the fertilized plots in 1961 ($P<.05$). This was the first year fertilizer could have been effective because it was not applied until the fall of 1960. In 1962, strobilus production in the fertilized plots was 33 percent greater than in unfertilized plots, but this difference was not significant ($P>.10$). Nitrogen alone increased strobilus production as much as did the complete fertilizer. Fertilizing brought about a deep, blue-green needle color and increased needle length. The deep, bluish-green color was more striking in NPK plots than in nitrogen-only plots.

Table 1.--Average female strobilus production per whorl before and after thinning (1959) and fertilizing (1960 and 1961), Units 1 and 2 combined[1]

Year	Spacing (ignoring fertilizer)			Fertilizer (ignoring spacing)		
	Unthinned	20'	30'	Unfertilized	N	NPK
	Number of strobili					
1959[2]	4.2	4.3	5.6	4.3	4.5	5.3
		---Thinned---				
1960	1.5	2.3	3.9	2.9	3.0	1.8
					--Fertilized--	
1961	2.1	7.1	8.5	3.6	7.0	7.1
					--Fertilized--	
1962	1.4	3.7	5.9	3.0	4.3	3.7

[1]Averages based upon strobilus counts for four whorls in each of three trees per 1/10-acre plot. The data for 1962 are based upon counts in six trees per plot.

[2]The number of female cones counted in the spring of 1960 was used to estimate production of 1959 female strobili before thinning and fertilizing.

Male Strobilus Production

Production of male strobili was significantly greater (P<.025) in the spring of 1960 on the trees released by thinning in October 1959 than on trees in the unthinned stand (table 2). Male strobilus production was also greater in the fertilized plots in 1961 and 1962 than on unfertilized plots, but the difference was not significant either year (P>.10). Strobilus production in 1962 was light and erratic.

Cone Length

Thinning caused a marked reduction in cone length (table 3). In 1960 no effect of treatment was noted. In 1961 the cones in unthinned plots were significantly longer than those in thinned plots (P<.025) and cones in plots with 20-foot spacing were significantly longer than those in plots with 30-foot spacing (P<.05). In 1962, cones in the unthinned plots were again significantly longer (P<.07) than cones in thinned plots.

Cones in fertilized plots were significantly longer than those in unfertilized plots in 1961 and 1962 (P<.005). In 1961 cones in plots receiving complete fertilizer were significantly longer (P<.05) than cones in plots receiving nitrogen only.

Sound Seed Per Centimeter of Cone Length

The effect of thinning and fertilizing upon the number of sound seed per centimeter of cone length was negligible.

Table 2.--Average production of male strobili per sample branch after thinning (1959) and fertilizing (1960 and 1961), Units 1 and 2 combined[1]

Year	Spacing (ignoring fertilizer)			Fertilizer (ignoring spacing)		
	Unthinned	20'	30'	Unfertilized	N	NPK
	Number of strobili					
		--Thinned--				
1960	140	303	363	265	305	236
					--Fertilized--	
1961	409	500	345	379	458	416
					--Fertilized--	
1962	119	62	76	8	102	146

[1]Average based on estimates of strobili on each of two branches on three trees per plot.

Table 3.--Average cone length (cm.) after thinning (1959) and fertilizing (1960 and 1961), Units 1 and 2 combined[1]

Year	Spacing (ignoring fertilizer)			Fertilizer (ignoring spacing)		
	Unthinned	20'	30'	Unfertilized	N	NPK
		--Thinned--				
1960	17.4	17.0	16.5	16.7	16.8	17.4
					--Fertilized--	
1961	18.0	17.2	16.2	15.8	17.2	18.3
					--Fertilized--	
1962	18.0	17.3	17.1	15.8	18.1	18.4

[1]Average cone length based on an average of six cones per tree, six trees per plot in 1960; five cones per tree, four trees per plot in 1961; and five cones per tree, six trees per plot in 1962.

Percentage of Hollow Seed

In all but one instance no significant difference in percentage of hollow seed was found for the treatments during the 3 years of seed collection. The only exception was in 1962 when treatment with complete fertilizer resulted in a significantly lower percentage of hollow seed ($P<.005$) than did treatment with nitrogen. Apparently there is sufficient pollen in the thinned area to maintain adequate production of sound seed on individual trees.

Seed Weight

Spacing had less effect on seed weight than did fertilizing (table 4). In 1961 and 1962 the seed weight in plots with 30-foot spacing was less than that in either the unthinned plots or those with 20-foot spacing. In 1961, the difference in seed weight between plots with 20- and 30-foot spacing was significant ($P<.07$).

Seed weight in fertilized plots was significantly greater ($P<.005$) than in the unfertilized plots in 1961 and 1962. Seed weight was 5 percent greater after treatment with complete fertilizer than after treatment with nitrogen in 1961 and 1962, but the difference was not significant ($P>.10$).

No significant difference ($P>.10$) was found in the weight of seed from infested and uninfested cones regardless of treatment.

Table 4.--Average weight per seed (mg.) after thinning (1959) and fertilizing (1960 and 1961), Units 1 and 2 combined[1]

Year	Spacing (ignoring fertilizer)			Fertilizer (ignoring spacing)		
	Unthinned	20'	30'	Unfertilized	N	NPK
		--Thinned--				
1960	16.2	16.2	16.2	16.0	16.7	15.8
					--Fertilized--	
1961	20.2	21.9	19.1	17.5	21.4	22.3
					--Fertilized--	
1962	18.5	18.3	18.0	16.4	18.7	19.8

[1]Averages based on seed collected from an average of six trees per plot, six cones per tree in 1960; four trees per plot, four cones per tree in 1961; and six trees per plot, five cones per tree in 1962.

Seed Production Per Tree

Data for production of female strobili, cone length, and average number of seed per centimeter of cone length were used to compute seed production per tree (table 5). To compute total strobilus production per tree, strobilus production based on the four-whorl sample was doubled. This adjustment was determined by complete counts of strobili on 24 trees that were topped in 1961 and on a second group of 12 trees (untreated sample trees in plots in the thinned stand). The total count for both groups was almost exactly twice the number of strobili in the four-whorl sample.

To account for overwinter loss, i.e., the difference between number of strobili produced and the number developing into mature cones the following spring, 10 percent was deducted from the total strobilus production per tree for each plot. This deduction was based upon a loss in strobili from June 1960 to June 1961, and from June 1961 to June 1962 of 11 percent and 8 percent, respectively.

Thinning significantly increased per-tree seed production in 1960 ($P<.025$), 1961 ($P<.005$), and 1962 ($P<.005$). Seed production in plots with 30-foot spacing was significantly greater in 1960 and 1962 than in plots with 20-foot spacing ($P<.08$ and $P<.05$, respectively).

Use of fertilizer significantly increased production per tree in 1961 ($P<.06$) and 1962 ($P<.05$). No significant difference was found between treatments with nitrogen and treatments with complete fertilizer.

Table 5.--Seeds produced per tree after thinning (1959) and fertilizing (1960 and 1961), Units 1 and 2 combined

Year	Spacing (ignoring fertilizer)			Fertilizer (ignoring spacing)		
	Unthinned	20'	30'	Unfertilized	N	NPK
		--Thinned--				
1960	8,143	13,540	21,128	16,095	16,533	10,183
					--Fertilized--	
1961	12,549	48,244	53,316	20,876	46,122	47,111
					--Fertilized--	
1962	8,833	25,562	37,638	17,580	27,631	26,822

Seed Production Per Acre

The seed production per acre was computed by multiplying the number of seed per tree by the actual number of trees per acre (table 6). The number of trees per acre was determined not by simply computing the theoretical number per acre for 9-foot, 20-foot, and 30-foot spacings, but by counting the trees in each plot. For the unthinned plots the number of trees was arbitrarily reduced by one-third before computing seed production per acre. This was done to account for intermediate and suppressed trees that would not produce as many cones as the average in unthinned sample plots. This reduction is thought to give a conservative estimate of seed production in the unthinned stand.

In 1960, the seed production in the unthinned plots was significantly greater than that in the thinned plots (P<.07). In 1961 and 1962, the difference between seed production in unthinned and thinned plots was not significant (P>.10), although the production in unthinned plots was greater in both years.

Use of fertilizer significantly increased seed production per acre in 1961 (P<.05) but not in 1962 (P>.10).

Table 6.--Seed production per acre after thinning (1959) and fertilizing (1960 and 1961), Units 1 and 2 combined

Year	Spacing (ignoring fertilizer) Unthinned	20'	30'	Fertilizer (ignoring spacing) Unfertilized	N	NPK
	--------------------Thousands of seed-----------------------					
		--Thinned--				
1960	2,912	1,212	1,604	2,137	2,265	1,326
					--Fertilized--	
1961	4,503	4,194	3,652	2,613	4,873	4,863
					--Fertilized--	
1962	3,182	2,250	2,794	2,399	3,187	2,640

Infestation by Cone Insects

The number of cones infested with larvae of cone moths (primarily Eucosma rescissoriana Heinrich) was estimated in 1960, 1961, and 1962 (table 7). The thinned plots consistently showed greater loss than the unthinned plots. In 1961, the loss in seed production in Unit 1 was serious, but in Unit 2 it was catastrophic: of the 32 trees bearing cones in the spring in the six plots in the thinned stand of Unit 2, only four trees bore uninfested cones in the fall. Only 3 percent of the total cones borne in spring by these 32 trees was uninfested when cones were collected in late August. Although cone insects do not ordinarily destroy the entire cone (3), the damage is serious. In 1961 and 1962, damage was great enough to preclude cone collection throughout the thinned stand. In 1962, insect activity was apparently somewhat greater in the adjacent unthinned area than it had been in previous years.

Genetic Gain

At most, little genetic gain in growth rate can be expected among trees reared from seed collected in the Cathedral Peak Seed Production Area. The selection intensity (only about 15 percent), method of selection, and heritability preclude achievement of more than minimal gain for any given trait, such as growth rate.

Seed trees were selected for the following characteristics in descending order of importance: freedom from blister rust, spacing, seed production, freedom from recurrent forking, good vigor, long crowns, and fine branching. Seed trees were chosen for several characters that probably have no significant correlation with growth rate. Consequently the growth rate of selected trees may not be significantly different from the mean of the whole population. Also, as Lush (15) demonstrated, the gain for any one character rapidly diminishes as the number of uncorrelated traits selected increases. A low heritability for growth traits apparently operates in juvenile western white pine, according to Squillace et al. (26) and Hanover and Barnes (11). This also would act to reduce the potential gain.

Table 7.--Estimated percentages of cones infested by insects in sample trees, Units 1 and 2 combined

Year	Spacing		
	Unthinned	20'	30'
1960[1]	10.0	15.0	32.2
1961[2]	11.8	56.4	65.8
1962[3]	22.0	69.7	79.2

[1]Estimates based on fall examinations of all cones counted in sample trees in the spring of 1960. Besides visibly infested cones, missing cones and cones that squirrels had cut were presumed infested.

[2]Estimates based on the number of cones infested out of the six best cones collected from each tree. This estimate is conservative since it does not consider many trees where collections were not made because all cones were infested.

[3]In thinned areas, estimates were based on fall examination of all cones counted in sample trees in the spring of 1962. In the unthinned plots, only cones on the tree at time of the fall examination formed the basis of the estimate, but many of them had been cut by squirrels.

Finally, no isolation strip was provided. The thinned areas were completely surrounded by unselected trees, and abundant exchange of pollen is highly probable.

DISCUSSION

The most interesting result was the significant increase (approximately 14 percent) in production of male strobili that occurred in the spring following heavy thinning in early October. This is apparently no anomaly since observations in thinned and unthinned portions of the stand confirmed the counts of strobili. It is reasonable to suppose that the thinnings acted to produce a more favorable physiological condition for (a) differentiation of strobili if this occurred after thinning and/or (b) preventing abortion of strobili if thinning occurred after differentiation of flowerbuds. Until further information is available on the differentiation of flowerbuds of western white pine, it would seem that either or both of these possibilities may explain the findings.

Considerable abortion of female flower buds is known to occur in the spring before pollination,[6] and this also is probably true for male flower buds. Thus, a working hypothesis is that abortion is a constant process that starts soon after differentiation of floral initials and continues after pollination. Abortion may be directly affected by the physiological condition of the shoot and subject indirectly to cultural treatments that alter this condition.

Applications of fertilizer late in the summer of 1960 resulted in a 96-percent increase in production of female strobili in 1961. Whether more buds were differentiated or less abortion occurred after differentiation was completed is unknown. Stephens (29) had similar results in an eastern white pine stand in Connecticut. He found that applying fertilizer in late July stimulated strobilus production the following year, but that treatment in early April the following year failed. The difference of approximately 1 month in time of summer application of fertilizer between

[6]Personal communication, R. T. Bingham, Intermountain Forest and Range Experiment Station, July 10, 1967.

the Idaho and Connecticut experiments probably is not important. In northern Idaho, summers are hot and exceedingly dry. Therefore, applications were made to coincide with the first early fall precipitation, which typically occurs in late August or early September. It would have been important to fertilize earlier if the summer season had been relatively wet.

As was observed in 1960, the technique for sampling male strobili was adequate to register only major changes in production. Apparently neither thinning nor fertilizing modified the large year-to-year differences.

The practical significance of this study is now essentially academic since unimproved stock of western white pine is not planted at present in the Rocky Mountains because of inability to protect this species from white pine blister rust (7). However, several comments are appropriate since similar conditions may exist for other species in this region and elsewhere.

Use of fertilizer significantly increased seed weight--some 21 percent. Two benefits from sowing heavier seeds--better germination and production of more vigorous seedlings--may be very important in nursery operations and regeneration. Mergen and Voight (18) concluded that the advantages of producing larger seeds sufficiently justified the cost of applying fertilizer.

Conventional seed production areas may be neither necessary nor economically justifiable in the future. Preparation of such areas and thinning of stands are expensive. Genetic gain for species propagated from seed collected from such areas is probably negligible. Moreover, such areas are subject to increased incidence of attack by destructive insects. Apparently an unthinned but fertilized stand would be as productive as a thinned, fertilized stand, and would be markedly safer from infestation until efficient, safe, economical measures for insect control are available. A light thinning, to remove suppressed and intermediate trees that typically do not flower, might further increase productivity without starting a sharp increase in insect attack.

Under the conditions stated above, the unthinned stand produced as much good seed per acre as the thinned stand. This conclusion must remain tentative because it is not known definitely that the number of trees per acre in the unthinned area, reduced by one-third, will actually produce the same average number of strobili per tree as trees in the sample plots. However, in the stands observed, a reduction of one-third seemed reasonable.

Seed production per tree may be more important than seed production per acre where the selected trees respond well to cultural treatments, where there is enough pollen, and where insect control can be guaranteed. Costs of seed collection would be lower if cones were concentrated in a few trees rather than scattered over many. However, if collecting by hand is difficult and hazardous, and if cones can be obtained from squirrel caches, fertilized stands that are unthinned or lightly thinned may prove to be more desirable economically and may produce as satisfactorily in both quantity and quality of seed as drastically thinned and otherwise more highly cultured stands.

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In a 40-year-old western white pine plantation developed as a seed production area, heavy thinning and application of fertilizer in the fall significantly increased strobilus production the following spring. Applying fertilizer increased seed weight and cone length significantly, but thinning did not. Insects severely damaged the cone crop in the thinned stand. This study indicates that abundant seed crops, relatively free from insect damage, may be produced without expensive thinning and area preparation operations.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)

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